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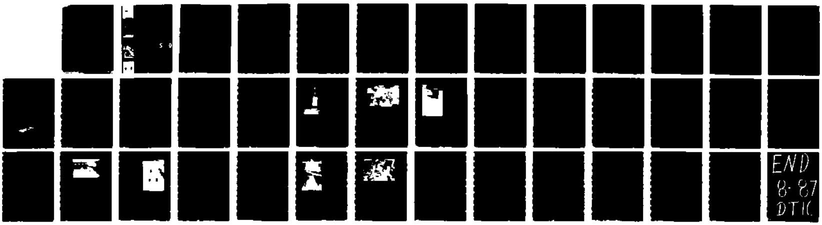

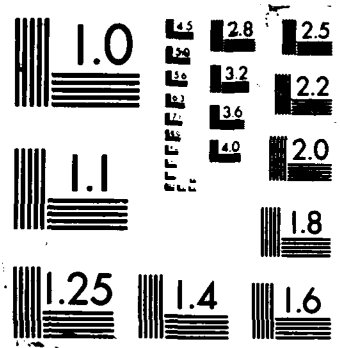

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AD-A182 235

FIELD VERIFICATION PROGRAM
(UPLAND DISPOSAL)

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PREDICTION OF SURFACE RUNOFF WATER QUALITY FROM BLACK ROCK HARBOR DREDGED MATERIAL PLACED IN AN UPLAND DISPOSAL SITE

by

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Dredging Operations Technical Support

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Interagency Field Verification of Methodologies for Evaluating Dredged Material Disposal Alternatives (Field Verification Program)

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The US Army Corps of Engineers is responsible for dredging millions of cubic yards of sediment from waterways every year. Some of this material is contaminated and must be tested to predict problems that might occur after disposal. The US Army Engineer Waterways Experiment Station (WES) Rainfall Simulator-Lysimeter System was developed to predict surface runoff water quality from dredged material placed in upland environments. Initial laboratory tests on dredged material placed in lysimeters showed that as the dredged material dried and oxidized, physicochemical changes occurred which changed the concentrations and form of contaminants found in surface runoff. These tests predicted that, initially, concentrations of suspended solids (SS) usually would be elevated and heavy metals would be poorly soluble and bound to the SS. As the material was dried and oxidized, SS concentrations in the runoff would decrease, and heavy metals such as copper (Cu), cadmium (Cd), zinc (Zn), nickel (Ni), and manganese (Mn) would increase in solubility.

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19. ABSTRACT (Continued).

The Field Verification Program was established to verify the accuracy, precision, and reproducibility of findings of the WES Rainfall Simulator-Lysimeter System, as well as other testing protocols. Sediment was collected from Black Rock Harbor, Bridgeport, Conn., placed in a laboratory lysimeter at the WES, and tested using the WES Rainfall Simulator-Lysimeter System. Sediment was dredged from the Black Rock Harbor and then placed in both confined wetland and upland disposal sites located on the property of the United Illuminating Power Company in Bridgeport. Dredged material collected from the upland disposal site was sampled and used in additional laboratory lysimeters at the WES. A series of rainfall simulations was applied to both the upland field plots and the laboratory lysimeters containing the dredged material using the WES Rainfall Simulator. Surface runoff samples were collected and analyzed for SS and for Cd, Cu, Zn, Ni, Mn, and Cr (chromium).

Filtered heavy metal concentrations were not statistically different between the two laboratory lysimeter tests and the field tests for either the wet, anaerobic or the dry, oxidized sediment or dredged material. Unfiltered concentrations of metals in surface runoff from the dredged material were less than concentrations in runoff from the initial sediment during the wet, anaerobic stage. These differences, however, were less than an order of magnitude and would not affect conclusions regarding potential adverse effects of surface runoff or potential control measures and restrictions. Unfiltered metal concentrations in surface runoff from the initial sediment were not statistically different from runoff concentrations from the dredged material during the dry, oxidized stage.

Results of this study showed that placement of Black Rock Harbor dredged material in an upland environment would allow physicochemical changes to occur that would significantly increase the solubility of Cd, Cu, Ni, Zn, and Mn. Filtered metal concentrations in surface runoff from dry, oxidized sediment would be statistically equal to unfiltered metal concentrations, indicating increased solubility of metals after dredged material was placed in an upland disposal site. ~~In addition,~~ filtered concentrations of Cd, Cu, and Zn would exceed the US Environmental Protection Agency Maximum Criteria for the Protection of Aquatic Life. With this information, Corps personnel can predict the potential impact of surface runoff from upland dredged material disposal operations in compliance with appropriate legislative mandates and regulations.

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EXECUTIVE SUMMARY

The US Army Corps of Engineers is responsible for the annual dredging of millions of cubic yards of sediment from the Nation's waterways and harbors. Most of this material is uncontaminated, poses few potential problems, and may be disposed of in an environmentally sound and economical manner. However, some dredged material is contaminated with heavy metals, PCBs, PAHs, pesticides, and other contaminants and may cause adverse environmental impacts if not disposed properly. Confined upland disposal has been the usual disposal alternative for these contaminated materials. This approach, however, is not without potential problems or impact areas. Impacts of confined upland disposal may be the result of the movement of contaminants through leachates, effluents during disposal, surface runoff, and plant and animal uptake.

Under the Long-Term Effects of Dredging Operations Program and the Environmental Impact Research Program (EIRP), the US Army Engineer Waterways Experiment Station (WES) has developed testing protocols for predicting the environmental impacts of contaminated dredged material placed in various disposal environments. One such protocol, the WES Rainfall Simulator-Lysimeter System developed under the EIRP, may be used for predicting surface runoff water quality from upland disposal sites resulting from storm events. Extensive calibration and field verification tests have previously demonstrated that the system is effective at predicting soil loss and runoff water quality from typical soil materials encountered in upland areas. However, because of the complex nature of dredged material and the extensive physicochemical changes that occur as the material dries and oxidizes, field verification of the Rainfall Simulator-Lysimeter System was required before widespread application of these procedures to contaminated dredged material disposed in an upland environment.

Field verification of the WES Rainfall Simulator-Lysimeter System was accomplished under the Field Verification Program. Sediment was collected from Black Rock Harbor, Bridgeport, Conn., and tested at the WES to predict surface runoff water quality. Bulk sediment analysis of the material indicated contamination with various heavy metals such as cadmium, copper, manganese, zinc, nickel, chromium, and mercury. Similar material was also dredged from Black Rock Harbor and placed in both a wetland and an upland disposal site on United Illumination Power Company property in Bridgeport.

Dredged material was collected from the upland disposal site and brought to the WES for additional laboratory surface runoff testing. Surface runoff water quality tests were conducted on both the laboratory lysimeters at the WES and at the upland Black Rock Harbor field site throughout the drying and oxidation period.

The results of this study demonstrated that the physicochemical changes that occur in dredged material placed in upland environments may significantly increase the solubility of heavy metals such as cadmium, copper, nickel, zinc, and manganese. These contaminants will potentially be more mobile and available, and thus more easily discharged into the surrounding environment through surface runoff, as well as in leachates, and taken up by plants and animals.

Results of this study also demonstrated that the WES Rainfall Simulator-Lysimeter System can predict surface runoff water quality from contaminated dredged material placed in upland environments. This test, in conjunction with other protocols and tests developed, provides the Corps with the necessary testing protocols to more appropriately assess and predict the environmental impacts of contaminated dredged material disposal. Informed decisions on the selection of disposal alternatives and possible control measures can be implemented in an environmentally sound manner, if necessary, prior to dredging.

PREFACE

This investigation was conducted by the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES) during the period 1982 to 1986. Funding for the study was provided by the US Army Corps of Engineers/US Environmental Protection Agency (EPA) Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives Program (Field Verification Program (FVP)). The FVP is sponsored by the Office, Chief of Engineers (OCE), and is assigned to the WES under the purview of the EL's Environmental Effects of Dredging Programs (EEDP). The OCE Technical Monitors for FVP were Drs. William L. Klesch and Robert J. Pierce. The objective of this program is to verify existing predictive techniques for evaluating the environmental consequence of dredged material disposal under aquatic, wetland, and upland conditions. The aquatic portion of the FVP study is being conducted by the EPA, with the wetland and upland portions conducted by WES.

The report was written by Mr. John G. Skogerboe, Dr. Charles R. Lee, Mr. Richard A. Price, Mr. Dennis Brandon, and Mr. George Hollins of the Contaminant Mobility and Regulatory Criteria Group (CMRCG), EL. The report was edited by Ms. Jessica S. Ruff of the WES Information Products Division.

Chemical analysis of samples from the lysimeter tests was conducted by the Analytical Laboratory Group (ALG), Environmental Engineering Division, EL, under the supervision of Ms. Ann B. Strong, Chief, ALG. Chemical analysis of field test samples was conducted by the US Army Engineer Division, New England, Water Quality Laboratory, under the supervision of Mr. Forest Knowles.

The study was conducted under the supervision of Dr. Lee, Chief, CMRCG; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. John Harrison, Chief, EL. Program Manager of the FVP was Dr. R. M. Engler.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.

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CONTENTS

PREDICTION OF SURFACE RUNOFF WATER QUALITY FROM BLACK ROCK HARBOR DREDGED MATERIAL PLACED IN AN UPLAND DISPOSAL SITE

PART I: INTRODUCTION

Background

Corps dredging

1. Millions of cubic yards of sediment are dredged from waterways and harbors every year in the United States. Some of this material may contain elevated concentrations of contaminants such as heavy metals, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and pesticides. The US Army Corps of Engineers (CE) is responsible for the dredging and disposal of much of this material and must evaluate all disposal alternatives. A wide range of disposal alternatives are available to the CE, including aquatic disposal, wetland creation, and upland disposal. When selecting an appropriate disposal site, the CE must consider numerous physical, chemical, biological, and economic factors that will determine the most suitable disposal alternative. The US Army Engineer Waterways Experiment Station (WES) has developed many tests to quantify and predict potential environmental impacts resulting from placement of contaminated dredged material in various disposal environments.

2. Confined upland disposal of dredged material is one disposal alternative that is often used, particularly for contaminated dredged material. Placement of freshwater and estuarine dredged material in an upland environment results in physiocochemical changes that may affect the mobility and availablity of contaminants (Gambrell, Khalid, and Patrick 1978; Folsom, Lee, and Bates 1981). Newly dredged sediment is generally anaerobic, with a neutral pH (pH = 7) and high moisture content (>50 percent). As the material dries and oxidizes, the dredged material pH can decrease to less than 7 and sometimes to less than 4 when high concentrations of sulfides and organic matter are present. During the wet, anaerobic stage, many of the contaminants are tightly associated with particulates as metal sulfides, and consequently are very poorly soluble. However, as the dredged material oxidizes, some of

these metals such as cadmium (Cd), copper (Cu), manganese (Mn), zinc (Zn), and nickel (Ni) may increase in solubility and availability. During large storm events, elevated levels of contaminants may be discharged from the disposal site as surface runoff, as well as leachates.

3. During the wet, anaerobic stage, the movement of contaminants will be mainly through the discharge of suspended solids. As the dredged material dries and oxidizes, the movement of contaminants may be increasingly through more soluble forms, and thus is more difficult to control. In addition, soluble contaminants are more available to plants and animals both on the site and in receiving waters, thus having a greater potential for adverse impacts.

4. Contaminants that are poorly soluble require very different controls than do soluble forms. Contaminants associated mainly with particulates can be controlled by allowing the suspended solids (SS) to settle out of the surface runoff before being discharged from the disposal site. Control measures could include the use of filters or settling ponds.

5. Soluble contaminants require different types of control or treatment measures. Options for control of dissolved contaminants could include catching or trapping all precipitation on the site, treating the runoff to remove the contaminants, or treating the dredged material to prevent the contaminants from becoming soluble. Catching and storing the surface runoff presents several problems if used as a long-term solution. Contaminants will remain in the dredged material and may become bioavailable, entering the food chain through plants and animals on the site. If the dredged material is estuarine, salt will be leached out of the material very slowly, and vegetation will be extremely difficult to establish.

6. Treatment of surface runoff is another option but may be expensive. An important advantage to surface runoff treatment is the eventual removal of the contaminants from the dredged material and the disposal site. Immobilization of the contaminants, through the addition of soil amendments such as lime and organic matter to make heavy metals less soluble, is relatively inexpensive. However, this treatment is uncertain and would require periodic monitoring in the future. Other options could include capping or appropriate consideration of mixing zones outside the site to dilute contaminated runoff although, as the public becomes more environmentally sophisticated, this option may become less viable.

7. Corps personnel responsible for disposal of the dredged material must know the environmental consequences if the material is to be placed in upland environments. Environmentally sound decisions can then be made when considering other disposal options or containment measures for controlling surface runoff. Because of the need to predict the environmental consequences of upland disposal of contaminated dredged material and the potential need for control measures, a method for predicting surface runoff water quality from a disposal site was required. Such techniques would aid CE Districts in selecting the most cost-effective and environmentally sound disposal alternatives. Disposal alternatives could then be evaluated, and if necessary, effective control or treatment measures could be implemented before environmental problems occur. The need to predict surface runoff water quality resulted in the development of the WES Rainfall Simulator-Lysimeter System.

Development of the WES Rainfall Simulator-Lysimeter System

8. The WES Rainfall Simulator is a modified version of a rotating disk-type rainfall simulator originally developed at the University of Arizona (Morin, Goldberg, and Seginer 1967). Rainfall simulators have been used for many years for conducting erosion, infiltration, and water quality tests and were an important tool in the development of the Universal Soil Loss Equation (Wischmeier and Mannering 1969). Until the rotating disk-type simulator was developed, rainfall simulators were plagued by an inability to simulate the kinetic energy of natural rainfall, which is vital for predicting erosion and infiltration (Morin, Cluff, and Powers 1970). To simulate the kinetic energy of natural rainfall, the rainfall simulator must duplicate the raindrop size distribution and the terminal drop velocity of natural raindrops. Earlier types of rainfall simulators were able to duplicate only one parameter or the other, and therefore could not accurately simulate the kinetic energy of natural rain. The rotating disk-type rainfall simulator was the first to duplicate both the drop size distribution and the terminal drop velocities of natural rainfall and was therefore selected for use in the WES Rainfall Simulator-Lysimeter System.

9. The WES Rainfall Simulator was similar to the original rotating disk-type rainfall simulator but had several important design modifications (Westerdahl and Skogerboe 1982). Instead of using only one simulator unit, the WES simulator utilized two units to provide larger surface coverage and a

longer slope length (Figure 1). In addition, each simulator unit was equipped with an adjustable slit disk opening that could be controlled by a programmable data trak controller that could instantly change the rainfall intensity. The WES Rainfall Simulator was tested and calibrated thoroughly to optimize the drop size distribution, terminal drop velocity, and rainfall intensity distribution over a standard plot area of 5.5 sq m (4.6 by 1.2 m). Calibration tests were conducted according to the methods used for other types of rainfall simulators (Meyer 1958). The calibration tests showed the WES Rainfall Simulator to be effective at simulating the drop size distribution and terminal drop velocities, and at achieving 95 percent of the kinetic energy of natural rain at a 5.08 cm/hr rainfall intensity.

10. The laboratory lysimeters used in the WES Rainfall Simulator-Lysimeter System were constructed of aluminum, with surface dimensions of 4.6 by 1.2 m. The lysimeter depth could be adjusted in increments of 15 cm to a total depth of 1.2 m. The lysimeter slope could also be varied from 0 to 20 percent. The laboratory lysimeters were lined with a polyethylene

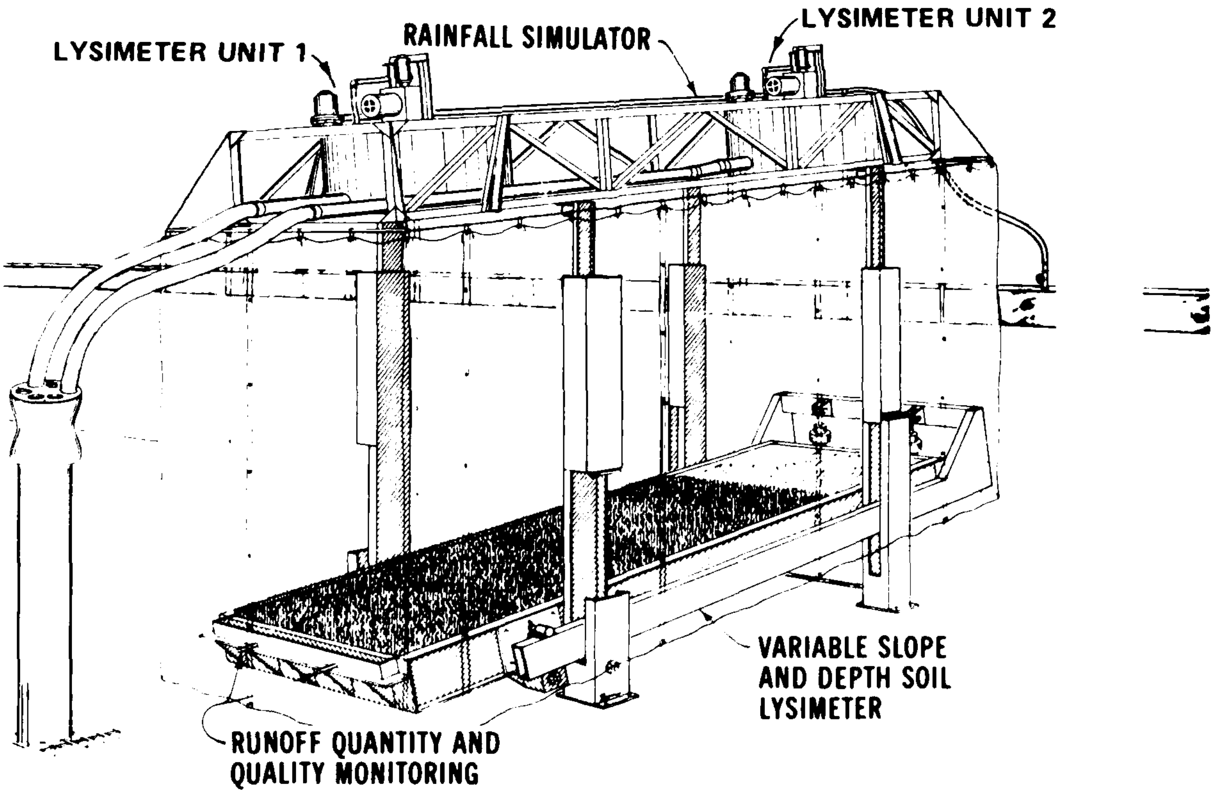

Figure 1. Schematic of the WES Rainfall Simulator-Lysimeter System

liner to prevent loss of material through cracks in the lysimeter as well as corrosion to the aluminum sides.

11. A series of laboratory and field verification tests were conducted after the WES Rainfall Simulator-Lysimeter System was calibrated. The first test was conducted in conjunction with the Overland Flow Wastewater Treatment Project conducted by the WES at Utica, Miss. Field plots, 45.5 by 4.5 m, had been established and equipped with automatic rainfall and runoff monitoring equipment (Peters, Lee, and Bates 1981). Blocks of soil were collected from one of the field plots and placed in two lysimeters at the WES with the existing vegetation on the soil surface (Westerdahl and Skogerboe 1982). A multiple-peaked natural storm event was selected from field data and programmed into the rainfall simulator data trak controller. Comparison of hydrographs for field and lysimeter data demonstrated that the system accurately simulated surface runoff from a natural storm event. Further analysis of SS concentrations in surface runoff demonstrated the WES System to be extremely sensitive to variations in plant biomass covering the study area. Regression analysis of log SS versus biomass resulted in correlation coefficients of r^2 greater than 0.95 on data collected from the lysimeters.

12. The relationship of biomass versus SS was further tested and field verified under the Environmental Impact Research Program (Lee and Skogerboe 1984). Field plots had been established on the Tennessee-Tombigbee Waterway, Divide Section to demonstrate restoration techniques for pyritic soil materials (containing iron disulfides) described in a WES Instruction Report (Lee et al. 1985). Soil material was collected from the field site, brought to the WES, and placed in two soil lysimeters. A series of rainfall simulations was conducted at different vegetation biomasses to quantify soil loss. Regression analysis of the biomass versus log SS again resulted in correlation coefficients of r^2 greater than 0.90. The WES Rainfall Simulator was then transported to the field site to conduct a similar series of tests on actual field plots. Comparison of results from the lysimeter and field tests showed no differences in SS concentrations at similar biomasses.

13. Results of extensive calibration work and testing demonstrated the effectiveness of the WES Rainfall Simulator-Lysimeter System for simulating natural storm events and for predicting soil loss and erosion from CE project sites. The WES system should therefore also be effective at predicting surface runoff water quality and contaminant release from CE upland dredged

material disposal sites. However, because of the complex nature of dredged material placed upland and the physicochemical changes that occur, further laboratory and field verification was required and accomplished under the Field Verification Program (FVP).

Purpose and Scope

14. This study addresses the evaluation of potential impacts on surface runoff water quality from an upland dredged material disposal site using the WES Surface Runoff Water Quality Test and verifies the predictive results of the test by observing the same parameters at an actual disposal site. This test provides the CE with a method for predicting potential adverse environmental impacts due to contaminants such as heavy metals, PCBs, and PAHs in surface runoff from an upland disposal site. The tests can be conducted prior to actual dredging and disposal and will enable CE Districts to fully evaluate the movement of contaminants in surface runoff, the need for control measures, and/or the need for restrictions on disposal of dredged material in upland environments. This advance testing will allow disposal alternatives to be formulated and selected prior to the dredging and disposal operation.

15. The field verification portion of this study will evaluate the effectiveness of the WES Rainfall Simulator-Lysimeter System for predicting surface runoff water quality from dredged material disposal sites. The results will demonstrate the system's ability to predict erosion rates, unfiltered and filtered contaminant concentrations in surface runoff, and the effects of physicochemical changes in dredged material that occur at upland disposal sites.

Approach

16. Sediment was collected from Black Rock Harbor, Bridgeport, Conn., prior to dredging and brought to the WES for testing using the WES Rainfall Simulator-Lysimeter System. Black Rock Harbor was then dredged, and the materials were placed in both an upland and a wetland disposal site at the United Illuminating Power Company in Bridgeport. Dredged material was collected from the Black Rock Harbor upland field site immediately after disposal and brought to the WES while still wet and anaerobic for further surface runoff water

quality testing. This additional dredged material was collected for further laboratory lysimeter surface runoff testing to determine the adequacy of the initial sampling. Surface runoff water quality tests were conducted on the Black Rock Harbor field site and on the lysimeters throughout the drying and oxidation process using the WES Rainfall Simulator.

17. Field verification tests concentrated on SS, pH, conductivity, Cd, Cu, Cr (chromium), Zn, Ni, and Mn; however, other contaminants such as PCBs, PAHs, mercury (Hg), arsenic (As), lead (Pb), and iron (Fe) were also quantified using the Lysimeter System. Preliminary studies had shown that Cd, Cu, Ni, Zn, and Mn would have a high probability of changing from less soluble forms to more soluble forms due to the physicochemical changes that would occur in the dredged material as it dries and oxidizes. Preliminary studies had also shown that Cr would remain poorly soluble compared to the other metals, and could therefore serve as a contrast to the others. To be fully successful, the lysimeter test should effectively duplicate the increased solubility of Cd, Cu, Ni, Zn, and Mn as well as the continued poor solubility of Cr when dredged material is placed in an upland environment and allowed to dry and oxidize.

PART II: MATERIALS AND METHODS

Sediment and Dredged Material Collection

18. Sediment was collected from Black Rock Harbor and placed in 200-ℓ barrels using a box core sampler in August 1982. The barrels of dredged material were transferred to the WES in a refrigerated truck and thoroughly mixed (Folsom and Lee 1982). The dredged material was then placed in a lysimeter (4.7 by 1.2 m) with a depth of 0.45 m to conduct surface runoff water quality tests to assist in predicting environmental impacts from future dredging and upland disposal operations.

19. In October 1983, the contaminated sediment was dredged from the Black Rock Harbor channel and placed in three disposal environments: upland, intertidal wetland, and aquatic (Figure 2). Material for the upland and wetland sites was placed in barges and towed to the disposal sites located at the United Illuminating Power Company in Bridgeport, Conn. The dredged material was slurried by adding water from the Bridgeport Harbor and pumped into the disposal sites where the dewatering process was initiated.

20. Dredged material was collected from the upland disposal site shortly after disposal for the purpose of conducting additional laboratory lysimeter surface runoff water quality tests. Because of the long time span between the initial sediment collection and the actual dredging, possible differences could have occurred due to new sediment or contaminant depositions in the Black Rock Harbor. A total of 25 barrels of dredged material were collected using the crane on the rainfall simulator trailer and a barrel attached to the hook (Figure 2). Dredged material was removed from the site, placed in clean barrels, sealed, and transported to the WES. Dredged material was poured from the barrels into two lysimeters (4.57 by 1.22 m, 11 barrels per lysimeter), thoroughly mixed, and allowed to settle (Figure 3). Water that remained on the surface was drained off prior to conducting rainfall simulations. The remaining three barrels were retained for dredged material characterization and plant and animal bioassays.

21. The initial sediment samples collected within Black Rock Harbor closely resembled those that would be representative of a clamshell dredging operation. However, because of the slurrying that was needed to move the dredged material from the barges to the upland/wetland disposal sites, the

Figure 2. Dredged material collection from the Black Rock Harbor upland disposal site

dredged material more closely resembled dredged material from a hydraulic dredging operation. The surface runoff water quality tests were conducted on the initial sediment samples according to procedures that would be used to test all future contaminated sediments, as described later in this report.

22. Very often, the method of dredging has not been selected before WES conducts its tests, and sometimes the selection of a dredging method is based on the results of those tests. Therefore, a standard method for conducting the WES Surface Runoff Water Quality Test was established. Since clamshell dredges are commonly used in the United States, particularly for contaminated sediments, the method selected resembled a clamshell dredging and disposal operation.

23. If hydraulic dredging is used on a contaminated sediment, the WES tests may overpredict initial SS and unfiltered contaminant concentrations due to a dilution effect caused by the added water from the hydraulic dredging. Laboratory tests have shown, however, that for the range of SS found in runoff

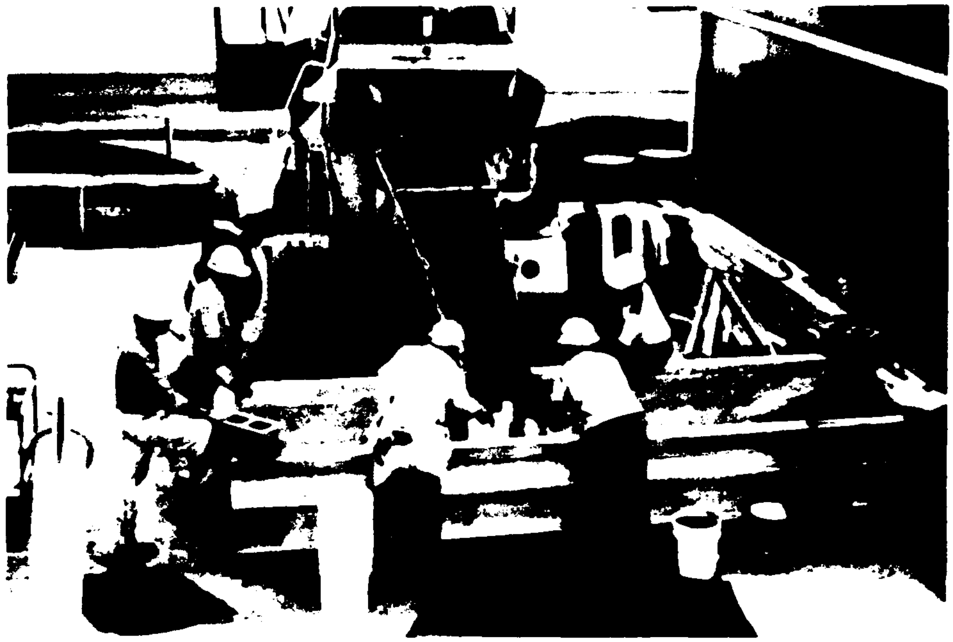

Figure 3. Placement of dredged material in laboratory lysimeters prior to testing

from wet, anaerobic dredged material, filtered metal concentrations would not be significantly affected by differences in sediment handling. After the material has dried and oxidized, the method of dredging and disposal would have little effect on the surface runoff water quality.

24. For field verification of the laboratory rainfall lysimeter surface runoff water quality tests, plots were established at the Black Rock Harbor field site identical in size to the lysimeters (4.57 by 1.22 m). Aluminum boxes were constructed at the WES and assembled in the field. The sides were 1.83 m high and were constructed for removal in 15-cm increments as the dredged material consolidated (Figure 4). Three field plots were constructed and lowered into the upland disposal site at or near the point where the dredged material was collected for the lysimeter tests.

Surface Runoff Water Quality Tests

25. Surface runoff water quality tests were initiated immediately after placing the sediment or dredged material in the laboratory lysimeters. A 5 cm/hr intensity storm event was applied to each lysimeter for 30 min. This

Figure 4. Construction of field rainfall simulator plots

intensity was selected because it was the standard storm intensity used for calibrating the rainfall simulator (Westerdahl and Skogerboe 1982) and has been used as a standard storm event for comparison to natural storm events (Laws and Parsons 1943). Similar rainfall intensities were also used in rainfall simulations for development of the Universal Soil Loss Equation (Wischmeier and Mannering 1969) and soil erosivity nomographs (Wischmeier, Johnson, and Cross 1971).

26. While 5 cm/hr for 30 min may be uncommon in different areas of the country, an intensity of 5 cm/hr for brief periods is not. In addition, it is the less common, high-intensity, high-volume storm events which contribute most to excessive erosion and runoff water quality problems. A single intensity and duration storm event was also selected to provide standardization and continuity to facilitate data analysis and comparisons of other future sites.

27. Simulated rainfall was acidified with sulfuric acid to a pH of 4.0 to 4.5, which was the average pH of rainfall for the Bridgeport area

(US Department of Energy 1983). Each lysimeter received two identical storm events at each stage of drying. One lysimeter was tested for the initial Black Rock Harbor sediment, and two lysimeters were tested for dredged material collected from the FVP upland disposal site.

28. Surface runoff from the laboratory lysimeter tests was monitored for runoff rates, SS, Cd, Cu, Cr, Mn, Zn, Ni, Pb, Hg, As, oil and grease, PCBs, and PAHs. Runoff was collected in a graduated cylinder once every minute for a duration of 10 sec, and the hydrograph was calculated. Runoff samples for SS and heavy metals were collected periodically in polyethylene bottles throughout the storm event. Samples for PCBs and PAHs were collected in glass bottles once, midway through the storm event. Procedures for determining runoff rates and collecting samples in the field were identical to those used on the laboratory lysimeters. Field-collected samples, however, were analyzed for only SS, pH, conductivity, Cu, Cd, Cr, Mn, Zn, and Ni. Initial laboratory testing showed that other parameters would be less than detectable limits in filtered samples and thus would provide very little useful information toward field verification of the laboratory lysimeter tests.

29. Samples for heavy metal analysis were divided into two portions--one was filtered for soluble metal analysis, and the other left unfiltered and used for total metals in surface runoff. All samples were preserved according to the Standard Methods for the Examination of Water and Wastewater. Field samples were chemically analyzed by the US Army Engineer Division, New England, Water Quality Laboratory, and the laboratory lysimeter samples were analyzed by the Analytical Laboratory Group, Environmental Laboratory, WES. Both laboratories used atomic absorption spectrophotometric analytical methods on filtered samples.

30. Different analytical methods were used on the unfiltered field samples. These were preserved according to Standard Methods but were analyzed as sediment samples due to the high concentrations of SS. The unfiltered lysimeter samples were also preserved but were acid digested and analyzed as water samples using a nitric acid digestion procedure from Standard Methods. The laboratory lysimeter values therefore had lower detection limits, which became particularly noticeable for the dry, oxidized tests. Analyses for PCBs and PAHs from the lysimeter tests were also conducted according to Standard Methods.

Statistical Analysis

31. An analysis of variance procedure was used to compare lysimeter and field results for both wet and dry dredged material. Analysis of variance is essentially an arithmetic process for partitioning a total sum of squares into components associated with recognized sources of variation (Steel and Torrie 1980). The two sources of variation were treatment (lysimeter or field) and error. The null hypothesis was that lysimeter concentrations equaled field concentrations. The alternate hypothesis was that lysimeter concentrations were not equal to field concentrations. These hypotheses were investigated for filtered and unfiltered samples separately. Rejection of the null hypothesis concludes that the lysimeter test did not accurately predict the field results.

32. The analysis of variance procedure was also used to compare filtered and unfiltered heavy metal concentrations. The null hypothesis was that filtered lysimeter concentrations equaled unfiltered lysimeter concentrations. The alternate hypothesis was that filtered lysimeter concentrations did not equal unfiltered lysimeter concentrations. Rejection of the null hypothesis concludes that filtered concentrations were not equal to unfiltered concentrations.

33. One-sided T-tests of significance were used to compare lysimeter runoff concentrations to US Environmental Protection Agency (EPA) Maximum Criteria for the Protection of Aquatic Life. Tests of significance allow one to compare the mean of one population to a specific value. The EPA criteria values were substituted into the tests of significance as the specific value for comparison. The null hypothesis was that lysimeter runoff concentrations were equal to or greater than the EPA criteria. The alternate hypothesis was that lysimeter concentrations were less than the EPA Criteria. In cases where the EPA Criteria were a range, the lower limit was used. Rejection of the null hypothesis concludes that no restrictions should be placed on surface runoff. The T-test and tests of significance have $P = 0.05$ of a type I error unless otherwise stated. Because the most likely receiving area for discharged surface runoff was some type of aquatic environment, the EPA Maximum Criteria for the Protection of Aquatic Life were selected as the criteria for comparison to surface runoff (Lee et al. 1985).

PART III: RESULTS AND DISCUSSION

Dredged Material Characterization

34. The Black Rock Harbor dredged material placed in the upland disposal site was characterized as mostly fine-grained sands (87 percent), with 9 percent clay and 4 percent silt (Table 1). The initial pH was 7.6, and the salinity was 25.3 ppt. Total sulfur was also high (1.3 percent) and resulted in very low pH values in the dry, oxidized dredged material in the field (pH <4.0). Heavy metal concentrations were very high, particularly Cd, Cu, Cr, Zn, and Pb.

35. The initial dredged material moisture content was very high: 90 percent for the Black Rock Harbor field site and the laboratory lysimeters containing the dredged material from the field disposal site, and 56 percent for the initial sediment collected from Black Rock Harbor. The difference in moisture between the initial sediment and the dredged material was the result of the collection and disposal methods. As the dredged material consolidated and settled, the resulting surface water was allowed to evaporate and be released through a discharge weir. Dredged material and sediment placed in the laboratory lysimeters was dewatered by siphoning the water from the surface as the material settled.

Comparison of Surface Runoff Water Quality Tests from Laboratory Lysimeter and Field Tests

36. Surface runoff water quality from Black Rock Harbor sediment and dredged material placed in an upland environment was quantified at WES using the WES Rainfall Simulator-Lysimeter System. Two sets of laboratory lysimeter test results were included in this report--the first set from the initial sediment collected directly from the Black Rock Harbor, and the second from the dredged material collected from the upland disposal site. The field runoff data were used to verify the accuracy of the lysimeter data.

Wet, anaerobic sediment and dredged material

37. Despite differences in the methods of sediment collection and disposal, the WES surface runoff water quality tests conducted on the initial

Table 1

Characterization of Black Rock Harbor Sediment and Dredged Material

Parameter	Concentration
Percent sand	87
Percent silt	4
Percent clay	9
pH	7.6
Salinity	25.3
Conductivity, dS/m	35.7
Total sulfur, %	1.3

Heavy Metals	Initial Sediment µg/g	Dredged Material µg/g
Cd	22.7 +1.18	27.7 +1.15
Cu	2,810 +171	2,520 +73.2
Cr	1,450 +211	1,650 +15.1
Zn	1,345 +66.1	1,620 +75.2
Ni	198 +16.7	180 +3.90
Mn	305 +18.6	*

* Value not available.

sediment predicted the filtered metal concentrations in surface runoff from the dredged material collected over 1 year later. Comparison of the first set of lysimeter tests conducted on the initial sediment to the second lysimeter and field tests conducted on the dredged material showed that the moisture content had no statistically significant effect on the filtered heavy metal concentrations (Table 2), except for Cr. The difference in filtered Cr concentrations, however, was less than an order of magnitude.

38. Unfiltered heavy metal concentrations from the initial sediment laboratory lysimeter tests were statistically higher than unfiltered concentrations from the laboratory lysimeter and field tests with the dredged material. Unfiltered metal concentrations from Black Rock Harbor field site were not statistically different from the laboratory lysimeter filled with the same dredged material. The added water from hydraulic disposal of the dredged material did cause a dilution effect, so that WES Surface Runoff Water Quality Test overpredicted unfiltered heavy metal concentrations. However, these differences were less than an order of magnitude.

Table 2

Surface Runoff Water Quality from Wet, Anaerobic Sediment and Dredged Material

Parameter	Initial Sediment Lysimeter	Dredged Material Lysimeter	Dredged Material Field
SS, mg/ℓ	12296 a	10326 +5040 a	9247 +6049 a
pH	7.6 a	7.8 +0.07 a	7.5 +0.18 a
Conductivity, mV/cm	7.3 a	10.5 +1.02 a	6.7 +0.98 a
	Unfiltered Heavy metals, mg/ℓ		
Cd	1.172 a	0.328 +0.104 b	0.218 +0.173 b
Cu	102 a	34.6 +15.2 b	24.5 +17.3 b
Mn	11.5 a	3.83 +1.51 b	2.61 +1.73 b
Ni	6.48 a	2.04 +0.965 b	1.63 +1.02 b
Zn	53.7 a	16.0 +7.08 b	16.1 +11.4 b
Cr	61.2 a	19.3 +8.87 b	15.7 +8.57 b
	Filtered Heavy Metals, mg/ℓ		
Cd	0.005 a	0.005 +0.002 a	0.0004 +0.0002 b
Cu	0.058 a	0.011 +0.005 a	0.008 +0.012 a
Mn	0.022 a	0.112 +0.026 a	0.102 +0.034 a
Ni	0.021 a	0.013 +0.012 a	0.012 +0.005 a
Zn	0.05 a	0.120 +0.087 a	0.081 +0.036 a
Cr	0.014 a	0.004 +0.001 b	0.002 +0.002 b

Note: Concentrations from different tests followed by the same letter are not statistically different at (P = 0.05).

39. The small differences in the prediction of surface runoff water quality due to different methods of dredging and disposal should, therefore, not affect conclusions on potential adverse environmental impacts due to surface runoff water quality, change recommendations for other disposal alternatives, or change the need for restrictions and controls if the dredged material were placed in a confined upland disposal site. The filtered concentrations represented the soluble fractions of heavy metals which are more mobile and available, and therefore the most important factor to consider in addressing potential adverse environmental impacts. The filtered concentrations were also the basis for comparison of surface runoff to water quality criteria, such as the EPA Maximum Criteria for the Protection of Aquatic Life.

Dry, oxidized sediment
and dredged material

40. Comparison of surface runoff water quality results from the two lysimeter tests and the field test on dry, oxidized sediment and dredged material showed no statistical differences from either the unfiltered or filtered heavy metal data. Small differences that had occurred in surface runoff from the wet, anaerobic condition no longer existed once the materials had dried and oxidized. Both laboratory lysimeter tests predicted the physicochemical changes that occurred when the dredged material was placed in the actual confined upland disposal site. Filtered concentrations of Cu, Mn, Zn, Ni, and Cr were not statistically different; however, both laboratory lysimeter tests overestimated the filtered concentration of Cd. The laboratory lysimeter tests did predict the increased solubilities of Cd, Cu, Mn, Zn, and Ni, as well as the continued poor solubility of Cr, which was verified at the Black Rock Harbor field site.

41. The only significant difference between the laboratory lysimeter tests and the field tests was that surface runoff pH was statistically lower in the field. Management of the Black Rock Harbor field site to prevent contaminants from being discharged from the site may have caused these differences. After the initial dewatering of the field site, the outlet weir at the field site was controlled to prevent surface runoff from being discharged from the disposal site. All surface runoff from the laboratory lysimeters, however, was completely removed from the lysimeter. During the first 5 to 6 months of drying and oxidation, moisture contained in the dredged material was being leached to the surface along with acid-forming materials such as sulfides. As the moisture evaporated, the acid-forming materials were deposited on the surface and then redissolved during storm events, either simulated or natural. Because the runoff was discharged from the laboratory lysimeter and not from the field site, acidity would have been removed from the laboratory lysimeter and trapped on the field site, resulting in a lower pH in the field. Heavy metals during the first 5 to 6 months were poorly soluble and would not have been leached from the material until later. The potentially low pH that occurred at the field site could, however, be predicted using techniques developed to predict lime requirements on acid mine materials. These tests were conducted on the initial sediment for plant bioassay and vegetation establishment tests, and did indicate the potential for a very low

sediment pH. This condition can greatly inhibit establishment of vegetation on the disposal site and can adversely affect vegetation outside the site due to very acidic surface runoff. By routinely applying lime requirement tests to dredged material placed in upland disposal sites, potential pH problems can be predicted and easily corrected with the appropriate application of lime.

42. The results of the surface runoff water quality tests demonstrate that a contaminated sediment can be collected from a waterway, brought to the WES, and tested using the WES Rainfall Simulator-Lysimeter System to accurately predict surface runoff water quality. The results also showed that the initial sediment sampling can be conducted up to a year in advance and still be representative of the dredged material deposited later. Results of the surface runoff tests on the dry, oxidized material also demonstrated that sediment can be placed in laboratory lysimeters and the physicochemical changes that occur will be very similar to those that take place at an actual disposal site. The WES Rainfall Simulator-Lysimeter System will predict which heavy metals will become soluble, as well as their concentrations in surface runoff.

Effects of Drying and Oxidation on Surface Runoff Water Quality

43. During the wet, anaerobic stage, the dredged material placed in the upland Black Rock Harbor field site had a very high moisture content, 90 percent (Figure 5). As the dredged material dried, the surface hardened and cracked (Figure 6). Surface runoff water quality tests initially resulted in very high SS concentrations but declined rapidly as the dredged material dried (Figure 7). Dredged material pH was the controlling factor in runoff pH and remained high (pH >7.0) for several months (Figure 8). Heavy metals during the wet, anaerobic period were poorly soluble and were bound tightly to the SS (Table 3). Solubilities of metals except for Mn were less than 5 percent of the total concentration, and filtered concentrations for all metals were statistically less than unfiltered concentrations.

44. Despite the poor solubility of the heavy metals in the wet, anaerobic dredged material, filtered concentrations for several metals were initially equal to or greater than the EPA Maximum Criteria for the Protection of Aquatic life (Table 3). Filtered concentrations of Cd, Cu, and Zn were equal to or greater than the criteria, and therefore deserve special consideration

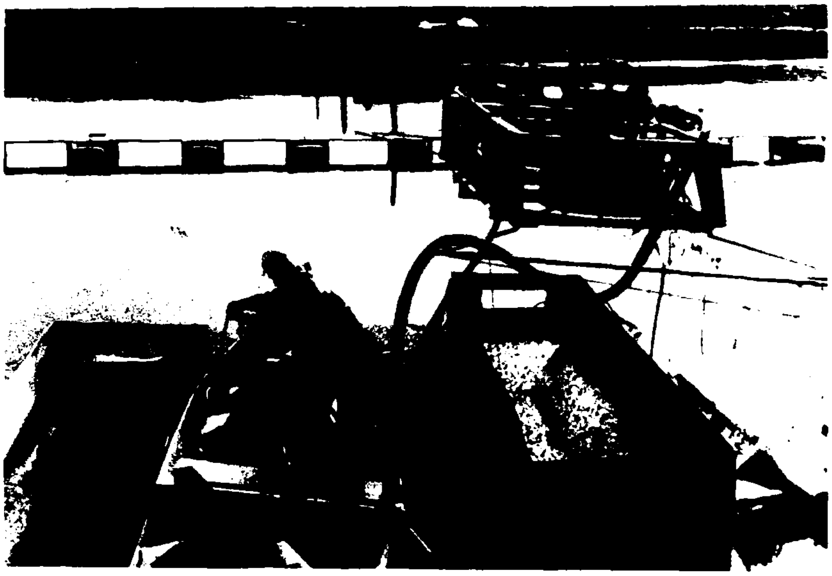

Figure 5. Wet, anaerobic dredged material at the Black Rock Harbor field site

for control measures or mixing zones outside the disposal site during this stage of dredged material consolidation and drying. During this period, concentrations of filtered and unfiltered metals declined rapidly along with the SS concentrations as the dredged material dried. The duration of the wet, anaerobic period where metals were poorly soluble was relatively short (<6 months) when compared to the much longer indefinite time period for the dry, oxidized dredged material. The transition from wet, anaerobic dredged material to dry, oxidized dredged material with respect to soluble heavy metals in surface runoff appears to require 5 to 6 months. This process is dependent on several factors, including dredged material moisture, length of time that the material is exposed to the atmosphere, and weather (i.e., precipitation, freezing, and thawing). Further research on different dredged materials under different conditions is necessary to more reliably determine exactly when this transition will occur. More consideration and emphasis should therefore be placed on the results of the runoff tests from the dry, oxidized dredged material, which has a greater potential for long-term adverse environmental impacts.

45. As the dredged material dried, a very hard crusted surface formed with extensive cracking that was resistant to the erosive effects of rainfall and the resulting runoff (Figures 9 and 10). Consequently, SS concentrations

Figure 6. Anaerobic dredged material beginning to dry and crack

in runoff samples were decreased to 151 mg/ℓ (Table 4). Filtered concentrations of Cd, Cu, Ni, Zn, and Mn were not statistically different from unfiltered concentrations and were present primarily in soluble forms. Only filtered concentrations of Cr were statistically lower than the unfiltered concentrations. Contaminants such as PCBs, PAHs, Hg, and As were below detection limits in both the filtered and unfiltered samples and were of no concern in surface runoff from this dredged material.

46. Comparison of filtered concentrations in surface runoff from dry, oxidized material with the EPA Maximum Criteria for the Protection of Aquatic Life shows that Cd, Cu, and Zn were equal to or greater than the criteria and could pose a regulatory concern (Table 3). Filtered concentrations of Cr and Ni were below the EPA Criteria and were considered to have little potential for adverse environmental impacts.

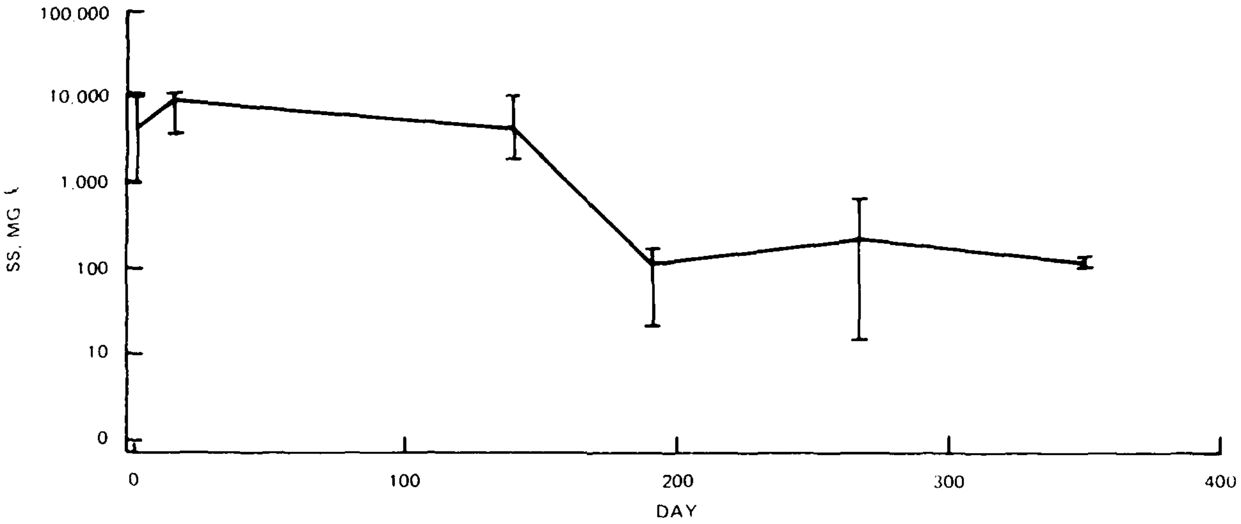

Figure 7. Mean suspended solids concentrations versus time in surface runoff from dredged material placed in the Black Rock Harbor field site

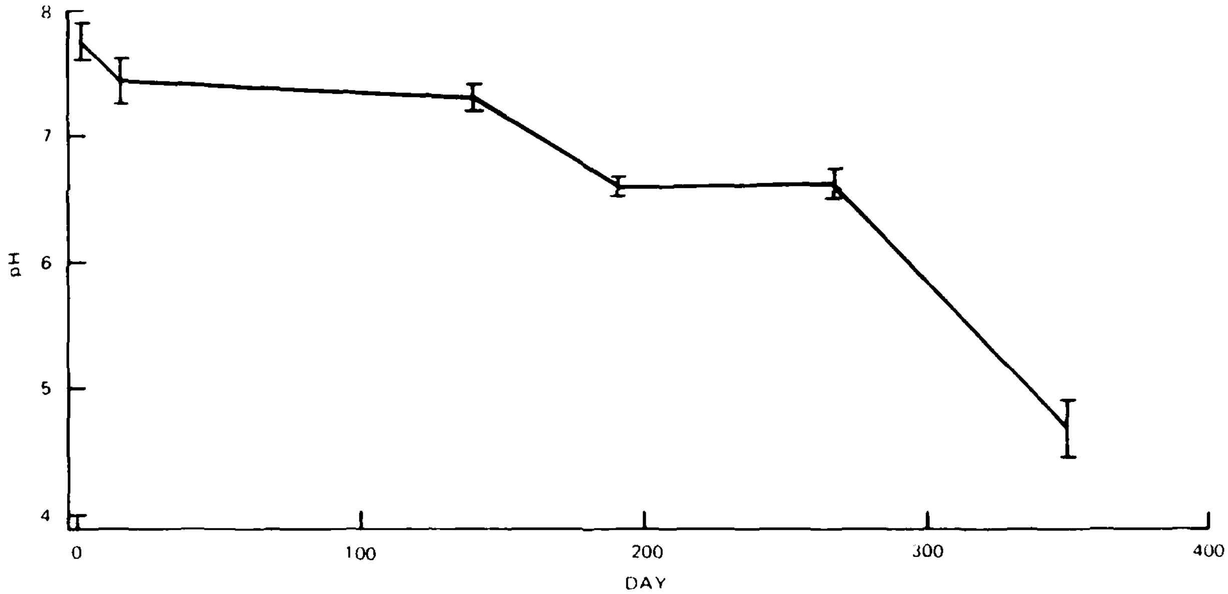

Figure 8. Surface runoff pH versus time after dredged material disposal in the Black Rock Harbor field site

Need for Control Measures and Restrictions

47. The results of the surface runoff water quality tests will be used in conjunction with other testing protocols to determine the environmental impacts of disposal in a confined upland disposal site. If the Black Rock Harbor dredged material were determined to have the potential for causing

Table 3

Effects of Drying and Oxidation on Surface Runoff Water Quality from the Black Rock Harbor Field Site

Parameter	Field Unfiltered	Field Filtered	EPA Maximum Criteria
	Wet, Anaerobic Dredged Material		
SS, mg/ℓ	9,247	†	†
pH	7.5	†	†
Cond., mV/cm	6.7	†	†
Cd, mg/ℓ	0.218	0.0004	0.0015-0.0024
Cu, mg/ℓ	24.5	0.008*	0.012-0.043
Ni, mg/ℓ	1.63	0.012	1.3-3.1
Zn, mg/ℓ	16.1	0.081*	0.180-0.570
Mn, mg/ℓ	2.61	0.102	†
Cr, mg/ℓ	15.7	0.002	2.2-9.9
	Dry, Oxidized Dredged Material		
SS mg/ℓ	151	†	†
pH	4.7	†	†
Cond., mV/cm	6.0	†	†
Cd, mg/ℓ	<0.030	0.016*,**	0.0015-0.0024
Cu, mg/ℓ	1.90	1.47*,**	0.012-0.043
Ni, mg/ℓ	<0.520	0.188**	1.3-3.1
Zn, mg/ℓ	2.98	3.07*,**	0.180-0.570
Mn, mg/ℓ	<0.100	0.740**	†
Cr, mg/ℓ	0.293	0.016	2.2-9.9

* Filtered concentrations were statistically equal to or greater than the EPA Maximum Criteria for the Protection of Aquatic Life (P = 0.05).

** Filtered concentrations were not statistically different from unfiltered concentrations (P = 0.05).

† No value available.

adverse environmental impacts, other disposal alternatives could be selected, a mixing zone could be considered, or control measures and restrictions could be implemented.

48. Potential problems from surface runoff may be in the form of excessive SS during the wet, anaerobic stage and soluble metals during the dry, oxidized stage. A mixing zone could be considered that would have the effect of diluting contaminant concentrations to an acceptable level to minimize impacts on the receiving water. The size of mixing zone required for dilution of surface runoff would depend on the physical and chemical characteristics of the receiving water (Peddicord et al. 1986) which include water

Figure 9. Dry, oxidized dredged material in a laboratory lysimeter

depth, current velocities, and background concentrations of the contaminants. If a mixing zone were considered to be unacceptable, then some form of control measures or restrictions may be considered.

49. During the wet, anaerobic stage, the most effective control would be to prevent surface runoff from being discharged from the disposal site or to detain the surface runoff and allow the SS and the associated contaminants to settle out of the runoff before being discharged. Most of the contaminants would thus be prevented from being discharged from the disposal site. Because of the high concentrations of soluble heavy metals such as Cd, Cu, Mn, Ni, and Zn in surface runoff from dry, oxidized dredged material, consideration of a mixing zone or control measures will be required for soluble contaminants. The most important contaminant of concern was Cd, which was approximately 100 times greater than the EPA Maximum Criteria for the Protection of Aquatic Life. Consideration of a mixing zone should be based on the filtered Cd


Figure 10. Dry, oxidized dredged material at the Black Rock Harbor field site

concentrations, as well as the physical and chemical characteristics of the receiving water. If a mixing zone for soluble Cd were determined to be unacceptable, other control options such as capping, runoff treatment, or dredged material treatment should be evaluated.

Table 4

Surface Runoff Water Quality from Dry, Oxidized Sediment and Dredged Material

Parameter	Initial Sediment Lysimeter	Dredged Material Lysimeter	Dredged Material Field
SS, mg/ℓ	320 a	167 +41 a	151 +[illegible] a
pH	6.7 a	6.2 +0.07 a	[illegible] a
Conductivity, mV/cm	4.9 a	5.3 +1.2 a	6.0 +1.[illegible] a
Unfiltered Heavy Metals, mg/ℓ			
Cd	0.110 a	0.133 +0.109 a	<0.030
Cu	1.05 a	0.970 +0.339 a	1.90 +2.1 a
Mn	0.295 a	0.190 +0.085 a	<0.100
Ni	0.150 a	0.183 +0.039 a	<0.520
Zn	1.10 a	3.62 +1.40 a	2.98 +2.[illegible] a
Cr	0.650 a	0.255 +0.113 a	0.29[illegible] +0.15 a
Filtered Heavy Metals, mg/ℓ			
Cd	0.08 a	0.112 +0.111 a	0.016 +0.0[illegible] b
Cu	0.109 a	0.622 +0.168 a	1.4[illegible] +2.02 a
Mn	0.158 a	0.158 +0.080 a	0.740 +0.[illegible] a
Ni	0.090 a	0.128 +0.045 a	0.188 +0.19 a
Zn	0.43 a	1.06 +0.463 a	3.07 +2.84 a
Cr	0.01 a	0.008 +0.001 a	0.016 +0.01 a

Note: Concentrations from different tests followed by the same letter are not statistically different at P = 0.05.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

50. The purpose of the FVP was to demonstrate the effectiveness of numerous tests at predicting potential impacts resulting from disposal of contaminated dredged material. The WES Rainfall Simulator-Lysimeter System has been demonstrated to provide the Corps with an effective tool for predicting the surface runoff water quality from contaminated dredged material placed in upland environments. Surface runoff water quality from the initial sediment collected from Black Rock Harbor was not significantly different from surface runoff water quality from the actual dredged material collected more than a year later. Field tests using the WES Rainfall Simulator demonstrated that the physicochemical changes that occur in a sediment, when it is allowed to dry and oxidize, are not significantly affected by placement in laboratory lysimeters at the WES. Small differences that may occur in unfiltered contaminant concentrations from wet, anaerobic sediment due to dredging and disposal methods do not significantly alter conclusions and recommendations concerning the potential impacts of surface runoff water quality on receiving waters.

51. The results of these tests, along with other tests being conducted under the FVP, will enable Corps personnel to make informed decisions concerning the most environmentally sound disposal alternatives for dredged material. If the material were placed in an upland site, planners would be able to predict potential environmental impacts that might occur from surface runoff prior to dredging, and appropriate restrictions and control measures could be implemented. If further testing of control measures were required, these tests could also be conducted before the sediment was dredged and placed in the disposal site.

52. For the particular case of the Black Rock Harbor dredged material, both the lysimeter tests and the field tests demonstrated that the placement of Black Rock Harbor dredged material in an upland environment has the potential for exceeding water quality criteria due to surface runoff water quality. During the wet, anaerobic stage, large quantities of SS could potentially be lost from the disposal site if proper control measures were not implemented. After the dredged material has dried and oxidized, the runoff SS and unfiltered heavy metal concentrations were significantly reduced, but soluble heavy metals increased and exceeded the EPA Maximum Criteria for the Protection of

Aquatic Life. Consideration of a sufficient mixing zone or the implementation of control measures or restrictions will be required for confined upland disposal of the Black Rock Harbor dredged material. Consideration of mixing zones and control measures and restrictions should be based on the filtered Cd concentrations from the dry, oxidized material, since Cd exceeds the EPA criteria for contaminants by the highest degree.

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